Foreword

Although the origins of distant signal transmission are ancient, the theoretical foundations of modern telecommunication techniques are owed to Claude Shannon's 1948 publications. Since then, the field of telecommunications has not stopped evolving. In particular, spread spectrum techniques enabled unprecedented improvements in the quality and security of digital communications under harsh transmission conditions.

Today, the main players in the telecommunication world are facing an increasing demand for multimedia wireless applications, linked to a real need for very high throughput radio communication systems. Among the most recent innovations in this field, the scientific community is particularly interested in ultra-wideband (UWB) technology. This technique consists of transmitting radio signals spreading over very large frequency bandwidths, typically in the order of 500 MHz to several GHz. Initially developed in the field of radar localization, UWB technology is now seen as a promising candidate for future wireless transmission systems. As such, it is considered with an increasing interest in both scientific and industrial communities.

UWB technology undeniably offers numerous advantages and unprecedented possibilities in the design of radio systems. Its very large spectral bandwidth optimally exploits the benefits of spread spectrum techniques, by increasing the transmission capacity and by improving the jamming immunity. Simultaneously, UWB presents a high resolution in the time domain, which may be used to efficiently process the multiple propagation paths or handle localization issues. In particular, the capacity of UWB pulses to travel through different materials allows us to consider through-wall imaging applications. It is also noteworthy that UWB systems present a low power spectral density, which not only increases the discretion and security of wireless communications, but also reduces the potential jamming experienced by other spectrum users. Finally, the complexity of

UWB transceivers may be considerably reduced with respect to traditional architectures.

These characteristics are unique to UWB technology and enable the design of communication systems offering very high data rates, up to several hundred Mbps. In 2002, the Federal Communication Commission (FCC) – an American regulation body – authorized the transmission of UWB signals in the 3.1–10.6 GHz band, encouraging the research efforts in this field in all continents. In Europe, a transmission mask for UWB signals has been defined and the coexistence between UWB systems and other applications is under study. In the current context of high demand for wireless multimedia applications, UWB seems to be an innovative and attractive solution for future radio communication systems. As an illustration, important industrial consortiums such as UWB Forum and WiMedia Alliance are currently involved in the design of UWB based equipment.

These systems are particulary well suited to ad hoc communication networks, but a number of other applications may be envisioned by exploiting the unique characteristics of UWB. The possibility of accurate localization enable the development of sensor networks known as radio frequency identification (RFID), for industrial environment applications or for mass market geographical information services. Radar identification techniques based on UWB signals may be exploited to design anti-collision systems for vehicles, but may also be used in the fields of civil engineering, medicine and imaging. Numerous applications still need to be explored, associating UWB with advanced techniques such as multiple-input multiple-output (MIMO) antennas techniques or time reversal techniques.

In order to develop such systems, many challenges are still to be encountered. The short duration of UWB signals requires a high accuracy in the system synchronization procedure. Also, electronic components need to be adapted in order to process such a wide frequency band, while maintaining a tractable complexity. In particular, the antenna characteristics largely vary with increasing frequency and require an accurate characterization.

Among these scientific challenges, a complete knowledge of the radio channel properties is fundamental. Indeed, the performance of a wireless transmission system is directly linked to the propagation conditions between the emitter and the receiver. These devices need to be designed in order to benefit from the channel characteristics and to mitigate the channel impairments. For instance, modeling the propagation loss allows us to estimate the radio system coverage, while link level simulations may be used to assess the communication robustness. Owing to the width of its frequency band, the

UWB propagation channel is intrinsically different from traditional wideband channels. For instance, the interactions between the radio waves and their environment need to be described more accurately and the variations of the material properties with frequency need to be taken into account. It is thus necessary to closely study the propagation channel in order to evaluate the potential and the constraints attached to UWB communication systems.

This textbook results from an intense collaboration between France Telecom's Research and Development Division and the IETR–UMR CNRS 6164 (*Institut d'Electronique et de Télécommunications de Rennes*/Institute of Electronics and Telecommunications in Rennes). These research teams conducted joint studies on UWB techniques and on the impact of the transmission channel on UWB communication systems. Through its didactic presentation and the detailed illustration of the discussed topics, this document is an excellent introduction for engineers and communication systems designers as well as for researchers and lecturers willing to expand their knowledge to the field of the UWB transmission channel. The originality of this textbook lies in its experimental approach, which allows the reader to follow step by step the theoretical and practical aspects of radio channel characterization and modeling. This approach may easily be adapted to different contexts: for different applications, in other environments or in different frequency bands, such as the available bands around 17 GHz and 60 GHz. It should also be noted that the accurate knowledge of the UWB channel in the 3.1–10.6 GHz band gives access to all the useful information for developing systems included in this frequency band, such as WiFi systems operating around 5 GHz.

This book is divided into five distinct parts.

Chapter 1 presents UWB technology. Its historical evolution, the envisioned applications and its main characteristics are detailed. UWB spectrum regulation issues and the proposed communications techniques are also discussed.

Chapter 2 describes the propagation of electromagnetic waves in general. All large scale and small scale radioelectric phenomena at play are highlighted. The reader is then introduced to the area of mathematical representation and its characteristic parameters. This didactic presentation covers both indoor and outdoor environments and is applicable in both contexts of mobile radio and wireless networks.

Chapter 3 presents an overview of the channel sounding techniques adapted to UWB technology. A distinction is made between frequency domain and time domain techniques, with a discussion on the application domains and the

limitation of each solution. The main UWB channel measurement campaigns available in the literature, including those conducted by the authors, are listed and illustrated by a few examples.

For the study of the propagation phenomena and the design of communication systems, the UWB propagation channel is simulated using deterministic or statistical models. These two modeling approaches are detailed and illustrated in the last two chapters. Chapter 4 focuses on deterministic UWB modeling. A literature review of the proposed deterministic models is given, comparing the advantages and drawbacks of each proposal. The fundamental issues and the theoretical formalism of a UWB deterministic model are then detailed. To illustrate this presentation, some examples are given, where the authors describe a comprehensive deterministic simulator for the UWB channel.

Chapter 5 is dedicated to the statistical modeling of the UWB transmission channel. The characterization of the most representative radio channel parameters is first presented. Different results available in the literature are compared and commented upon, hence providing a rich experimental database on the UWB propagation channel characteristics. After a description of different statistical models, the principles of statistical modeling and the different related issues are presented following an experimental method. This approach is illustrated using a model designed by the authors, allowing for the simulation of the UWB channel in both static and dynamic environments.

Finally, the interested reader will find useful additional information regarding channel analysis and modeling in the appendices. The discussed technical material includes the fields of signal processing, statistics, geometrical optics and diffraction theory. It should also be noted that the numerous bibliographical references constitute an abundant source of information, which may easily be exploited to learn more about the last advances in this field.

This book examines all the characteristics of the UWB transmission channel and provides useful tools for designing efficient UWB systems. Non-specialists will be introduced to UWB technology in general and more particularly to the propagation channel, which is the key element in a communication system. Specialists will find valuable information and a practical approach in order to design simulators, set-up measurements, study the channel characteristics and define models for UWB or in other contexts. This reference document is also an excellent basis for further research on advanced techniques, such as time reversal or UWB transmission in a MIMO

configuration. I am convinced that this textbook will prove essential reading in future research in the field of UWB communications.

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